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14. ABSTRACT We hypothesize that BRCA2 facilitates the formation and/or the function of the ternary ISGF3 complex and thus, functional BRCA2 protein is essential for the antiproliferative effects of type I interferons against human breast tumor cells. Specific aims: (A) To evaluate further the structural and functional interactions of BRCA2 with the members of the ISGF3 complex (STAT1, STAT2 and IRF9) in the human breast cells. (B) To evaluate the antiproliferative effects of BRCA2 over expression in the human breast cells with or without knock down of the IRF9 protein by RNA interference. (C) To evaluate the antiproliferative effects of type I interferons against tumors developed by BRCA2 positive and BRCA2 negative human breast tumor cells in the nude mice xenograft model.					
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**Role of BRCA2 in the expressions of IRF9-regulated genes in human breast cells PI:
Gautam Chaudhuri, PhD**

INTRODUCTION

BRCA2, a tumor suppressor whose inactivation is associated with hereditary breast and ovarian cancer predisposition, is essential for DNA repair in mammalian cells [1-5]. BRCA2-deficient cells are defective in the repair of DNA double-strand breaks by error-free homologous recombination [5, 6], allowing error-prone repair processes to create gross chromosomal rearrangements that may promote carcinogenesis [6]. The role of BRCA2 in homologous recombination has been linked to its functions in the regulation of RAD51, a RecA-related recombinase that forms the nucleoprotein filaments on damaged DNA that are crucial to recombinational repair [7, 8]. BRCA2 binds directly to RAD51 through 6 of the 8 BRC repeats,

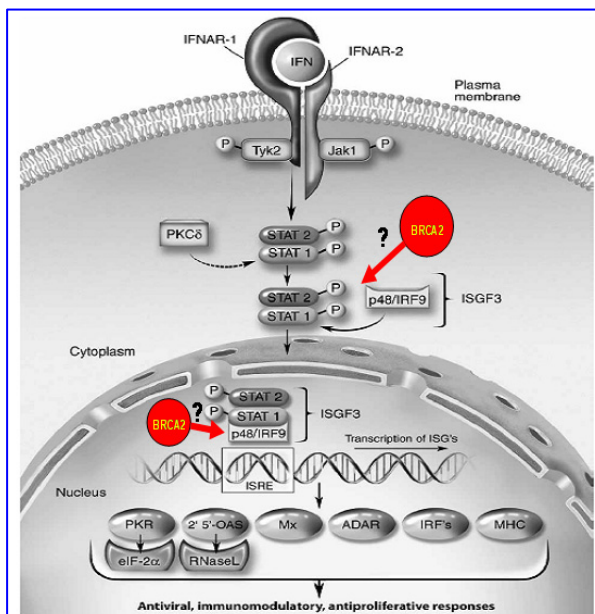


Fig. 5. Type I interferon (IFN) pathway. The predicted roles of BRCA2 (in red) are indicated.

~30 amino acid motifs encoded within the central exon 11 region of all known mammalian BRCA2 genes [6, 9-12]. In addition to its role in DNA double-strand break repair, BRCA2 also plays a role in stabilization of stalled DNA replication forks, cytokinesis, transcription regulation, mammalian gametogenesis, centrosome duplication, and suppression of cell proliferation [6]. However, how BRCA2 mutations predispose women specifically to breast and ovarian cancer remains undefined. One of the possible pathways for the antiproliferative effect of BRCA2 is mediated through the MAGE-D1 protein [13]. BRCA2 binds and stabilizes MAGE-D1, a member of the MAGE gene family of proteins. Expression of BRCA2 and MAGE-D1 synergistically suppresses cell proliferation independently of the p53 pathway. MAGE-D1 is a downstream target of BRCA2 and that BRCA2 suppresses cell proliferation via stabilizing MAGE-D1

[13].

We found that transient ablation of the breast cancer susceptibility gene BRCA2 in the human breast cells (Fig. 1) impairs the expressions of many type I interferon regulated genes. Thus, it appears that type I interferons need functional BRCA2 for their actions [14]. Thus, negative regulation of IFN-induced genes in BRCA2-ablated breast cells may reflect another growth regulatory role of BRCA2.

The interferons (IFNs), in addition to their well-known antiviral activities, have important roles in the control of cell proliferation and are effective agents for the treatment of malignant diseases. IFNs not only regulate cell growth and division but also influence cell survival through their effects on apoptosis. α and β interferons are type I IFN proteins with antitumor activity [15, 16]. They down regulate oncogene expression and induce tumor suppressor genes, which result in antiproliferative activity. The classic pathway induced by type I IFNs involves the interaction

of the IFN with two-receptor subunits, IFNAR-1 and -2, which are associated with TYK-2 and JAK-1, respectively [17-19]. TYK-2 and JAK-1 phosphorylate tyrosine residues on the receptor that provide docking sites for the src-homology-2 (SH2) domains of STATs in a cell type specific manner [15, 16]. Once phosphorylated, STATs are released from the receptor and form heterodimers. In response to Type I IFNs, STAT2 is recruited to the IFNAR1 chain, where it is phosphorylated by TYK-2 and serves as a lure for STAT1 [15, 16]. Once released from the receptor, the resulting STAT1:STAT2 heterodimer associates with IRF9, a DNA binding protein (also called p48), forming a complex named IFN-stimulated gene factor-3 (ISGF3). After formation, ISGF3 translocates to the nucleus where it binds to the IFN-stimulated response elements (ISRE) upstream of IFN response genes and initiates transcription (Fig. 1).

We hypothesize that BRCA2 facilitates the formation and/or the function of the ternary ISGF3 complex and thus, functional BRCA2 protein is essential for the antiproliferative effects of type I interferons against human breast tumor cells.

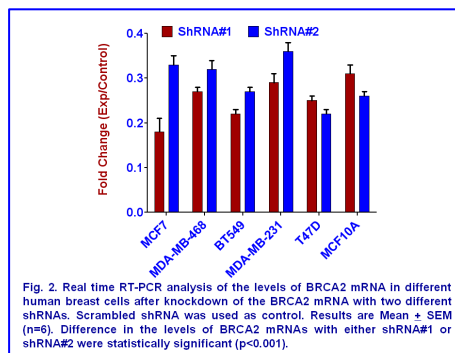
Specific aims to verify the hypothesis are: (A) To evaluate further the structural and functional interactions of BRCA2 with the members of the ISGF3 complex (STAT1, STAT2 and IRF9) in the human breast cells. (B) To evaluate the antiproliferative effects of BRCA2 over expression in the human breast cells with or without knock down of the IRF9 protein by RNA interference. (C) To evaluate the antiproliferative effects of type I interferons against tumors developed by BRCA2 positive and BRCA2 negative human breast tumor cells in the nude mice xenograft model.

BODY

Task outlined in the approved Statement of Work for this period of the project

Task#1

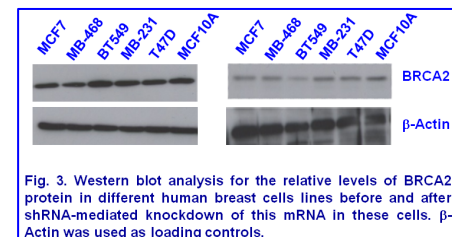
To evaluate further the structural and functional interactions of BRCA2 with the members of the ISGF3 complex (STAT1, STAT2 and IRF9) in the human breast cells. (Months 1-18)



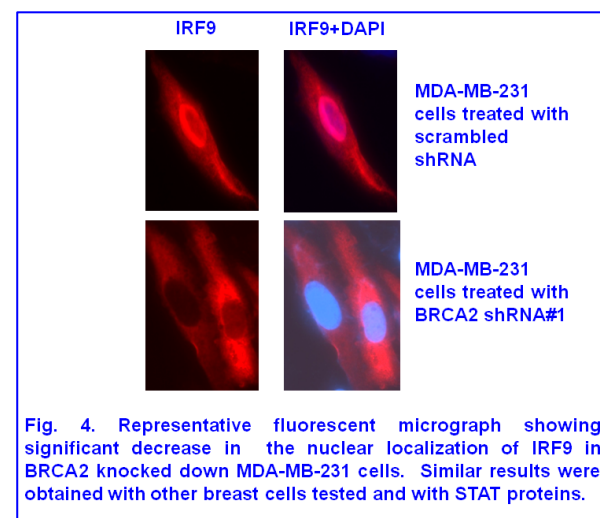
1. We knocked down BRCA2 gene expression in the following human breast cancer cells: MCF7, MDA-MB-468, BT549, MDA-MB-231, T47D and MCF10A. We used Sigma Mission validated lentiviral shRNA particles to knockdown the BRCA2 mRNAs. The puromycin-resistant clones are evaluated for BRCA2 mRNA and protein by qRT-PCR (Applied Biosystems) and Western blotting analysis (R & D Systems), respectively. The BRCA2 mRNA levels decreased 70-85% (Fig. 2) and the protein

levels decreased 55-65% (Fig. 3).

2. We evaluated the subcellular localization of ISGF3 complex in the control and BRCA2/KD cells. Our preliminary data suggested that BRCA2 binds with the components of ISGF3. The first question we asked is whether the nuclear localization of ISGF3 is affected in BRCA2 deficiency. We determined the subcellular locations of ISGF3 components by immunofluorescence confocal microscopy. We used commercially



available (Santa Cruz Biotech) antibodies against the ISGF3 component proteins for these experiments. For the detection of IRF9 we used ISGF-3 γ p48 (B-18): sc-101070, a mouse monoclonal antibody. For Stat1 we used Stat1 p84/p91 (H-95) sc-98783 rabbit polyclonal



3. We have developed a BRCA2 derivative that lacks only the nuclear localization signals but not the other C-terminal domains. We started with the pCINBRCA2WT plasmid, a clone of full-length human BRCA2 protein in pcDNA3 vector, a gift from Prof. Mien-Chie Hung of



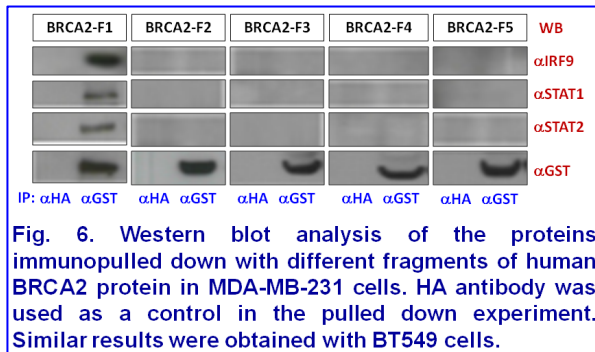
the recombinant clones. We will employ these recombinant cells to further verify the need for nuclear localization of the BRCA2 protein for the activation of the ISG15 gene promoter. We

will also use these cells for subcellular fractionation and co-immunoprecipitation to evaluate by Western blotting whether BRCA2-ISGF3 complex is formed in the cytosol. These data will be generated soon.

Task#2

To evaluate the antiproliferative effects of BRCA2 over expression in the human breast cells with or without knock down of the IRF9 protein by RNA interference. (Months 16-30)

1. We evaluated the ability of different domains of human BRCA2 protein in pulling down the components of the BRCA2/ISGF3 complex. Human BRCA2 is a large protein (3418 amino acids). We have amplified 5 consecutive fragments from the human BRCA2 ORF (in plasmid pCINBRCA2WT). There are five peptide fragments: the first 4 fragments are from the



N-terminal end and have 683 amino acids (ORF ~2055 bp with start and stop codons) and the 5th C-terminal fragment has 686 amino acids. We have cloned these PCR amplified products into N-terminal GST-tagged protein expression vector [pFN2K (GST) Flexi® Vector]. We expressed these N-terminal GST-tagged BRCA2 peptide fragments in human breast cells (Fig. 6). By GST-pull down assays we found that only the N-terminal 683 amino acid fragment of

BRCA2 was able to pull down all three components of the ISGF3 complex (Fig. 6). We conclude that BRCA2 interacts with the ISGF3 complex perhaps through the N-terminal domains. As it does not interact with its BRC repeats with ISGF3, ISGF3 will not compete with RAD51.

BRCA2-F1

MPIGSKERPTFFEIFKTRCNKADLGPIISLNWFEELSSEAPPYNSEPAEESEHKNNNYEPNLFKT
PQRKPSYNQLASTPIIIFKEQGLTLPLYQSPVKELDKFKLDLGRNVPNSRHKSLRTVKTKMDQAD
DVSCPLLNSCLSESPVVLQCTHVTPQRDKSVVCGSLFHTPKFVKGRQTPKHISESLGAEVD PDM
SWSSSLATPPTLSSTVLIVRNEEASETVFPHDTTANVKSIFYSNHDESLKKNDRFIASVTDSENT
NQREAASHGFGKTS GNSFKVNSCKDHIGKSMNVLEDEVYETVVDTSSEDSFSLCFSKCRTKNL
QKVRTSKTRKKIFHEANADECEKSKNQVKEKYSFVSEVEPNDDPLDSNVANQKPFESGSDKIS
KEVVP SLACEWSQLTSLGLNGAQMEKIPLLHISSCDQNISEKDLLDTENKRKKDFLTSENSLPR
ISSLPKSEKPLNEETVVNKRDEEQHLESHTDCILAVKQAI SGTSPVASSFQGIKKSIFRIRESP
KETFNASFSGHMTDPNFKKETEASESGLEIHTVCSQKEDSLCPNLI DNGSWPATTTQNSVALKN
AGLISTLKKKTNKF IYAIHDETSYKGKKIPKDQKSELINCSAQFEANAFEAPLTFANADSGLLH
SSVKRSCSQNDSEPTLSLTSSFGTILRKCSRNETCSNNTVIS

BRCA2-F2

QDL DYKEAKCNKEKLQLFITPEADSLSCLQEGQCENDPKSKKVSDIKEEVLAACHPVQHSKVE
YSDTDFQSQKSLLYDHENASTLILTPTSKDVLSNLVMI SRGKESYKMSDKLKGNNYESDVELTK
NIPMEKNQDVCALNENYKNVELLPPEKYM RVASPSRKVQFNQNTNLRVIQKNQEETTSISKITV
NPDSEELFSDNENNFVFQVANERNNLALGNTKELHETDLTCVNEPIFKNSTMVLYGDTGDKQAT
QVSIKKDLVYVLAENKNSVKQHIKMTLGQDLKSDISLNIDKIPEKNNDYMNKWAGLLGPISNH
SFGGSFRTASNKEIKLSEHNIKKSKMFFKDIEEQYPTSLACVEIVNTLALDNQKKLSKPQSINT

VSAHLQSSVVVSDCKNSHITPQMLFSKQDFNSNHNLTSPQKAEITELSTILEESGSQFEFTQFR
KPSYILQKSTFEVPENQMTILKTTSEECRDADLHVIMNAPSIGQVDSSKQFEGTVEIKRKFAGL
LKNDCNKSASGYLTDENEVGFRGFYSAHGTKLNVSTEALQKAVKLFSDIENISEETSAEVHPIS
LSSSKCHDSVVMFKIENHNDKTVSEKNNKCQLILQNNIEMTTGTFFVEEITENYKRNTENEDNK
YTAASRNSHNLEFDGSDSSKNDTVCIHKDETDLLFTDQHNICL

BRCA2-F3

KLSGQFMKEGNTQIKEDLSDLTFLEVAKAQEACHGNTSNKEQLTATKTEQNIKDFETSDTFFQT
ASGKNISVAKESFNKIVNFFDQKPEELHNFSLNSELHSDIRKNKMDILSYEETDIVKHKILKES
VPVGTGNQLVTFQGGPERDEKIKEPTLLGFHTASGKKVKIAKESLDKVKNLFDEKEQGTSEITS
FSHQWAKTLKYREACKDLELACETIEITAAPKCKEMQNSLNNDKNLVS IETVVPKLLSDNLCR
QTENLKTSKSIIFLKVKVHENVEKETAKSPATCYTNQSPYSVIENSALAFYTSCSRKTSVSQTS
LEAKKWLREGIFDGQPERINTADYVGNLYENNSNSTIAENDKNHLSEKQD TYLSNSSMSNSYS
YHSDEVYNDSGYLSKNKLD SGIEPVLKNVEDQKNTSFSKVISNVKDANAYPQTVNEDICVEELV
TSSSPCKNKNAAIKLSISNSNNFEVGPPAFRIASGKIVCVSHETIKKVKDIFTDSFSKVIKENN
ENKSKICQTKIMAGCYEALDDSEDILHNSLDNDECSTHSHKVFADIQSEEILQHNQNM SGLK V
SKISPCDVSLETS DICKCSIGKLHKS VSSANTCGIFSTASGKSVQVSDASLQ NARQVFSEIEDS
TKQVFSKVLFKSNEHSDQLTREENTAIRTPEHLISQKGFSYNV

BRCA2-F4

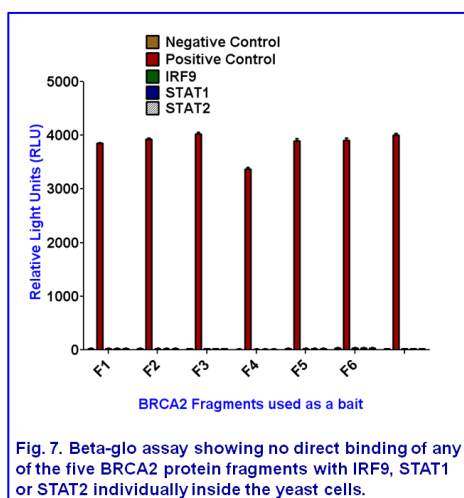
VNSSAFSGFSTASGKQVSILESSLHKVKGVLEEFDLIRTEHSLHYSPTSRQNVSKILPRVDKRN
PEHCVNSEMEKTCSEFKLSNNLNVEGGSSENNHSIKVSPYLSQFQQDKQQLVLG TKVSLVENI
HVLGKEQASPKNVKMEIGKTETFS DVPVKTNIEVCSTYSKDSENYFETEAVEIAKAFMEDDEL T
DSKLPSHATHSLFTCPENEEMVLSNSRIGKRRGEPLILVGEPSIKRNLLNEFDRIIENQEKSLK
ASKSTPDGTIKDRRLFMHHSVLEPITCVPFRTTKERQEIQNPNTAPGQEF LSKSHLYEHLTLE
KSSSNLAVSGHPFYQVSATRNEKMRHLIT TGRPTKVFPFPFKTKSHFHRVEQCVRNINLEENRQ
KQNIDGHGSDDSKNKINDNEIHQFNKNNSNQAAAVTFTKCEEEPLDLITSLQ NARDIQDMRIKK
KQRQRVFPQPGSLYLAKTSTLPRISLKA AVGGQVPSACSHKQLYTYGVSKHC IKINSKNAESFQ
FHTEDYFGKESLWTGKGIQLADGGWLI PSNDGKAGKEEFYRALCDTPGVDPKLISRIWVYNHYR
WIIWKLAAMECAFPKEFANRCLSPERVLLQLKYRYDTEIDRSR RSAIKKIMERDDTAAKTLVLC
VSDIISLSANISSETSSNKTSSADTQKVAIIELTDGWYAVKAQL

BRCA2-F5

DPPLLAVLKNGR LTVGQKIILHGAELVGSPDACTPLEAPESLMLKISANSTRPARWYTKLGFFP
DPRPFPLPLSSLFSDGGNVGCVDVIIQRAYPIQWMEKTSSGLYIFRNEREEEEEKAAKYVEAQQK
RLEALFTKIQEEFEEHEENTTKPYLPSRALTRQQVRALQDGAELYEAVKNAADPAYLEGYFSEE
QLRALNNHRQMLNDKKQAQIQLEIRKAMESAEQKEQGLSRDVTTVWKLRIVSYSKKEKDSVILS
IWRPSSDLYSLLTEGKRYRIYHLATSKSKSKSERANIQLAATKKTQYQQLPVSDEILFQIYQPR
EPLHFSKFLDPDFQPSCSEVDLIGFVVS VVKKTGLAPFVYLSDECYNLLAIKFWIDLNEDI IKP
HMLIAASNQWRPESKSGLLTLFAGDFSVFSASPKEGHFQETFNKMKN TVENIDILCNEAENKL
MHILHANDPKWSTPTK DCTSGPYTAQIIIPGTGNKLLMSSPNCEIYYQSPLSLCMAKRKSVSTPV
SAQMTSKSCKGEKEIDDQKNCKKRRALDFLSRLPLPPVSP ICTFVSPAAQKAFQPPRSCGTKY
ETPIKKKELNSPQMTPFKKFNEISLLESNSI ADEELALINTQALLSGSTGEKQFISVSESTRTA
PTSSSEDYLR LKRRCTTSLIKEQESSQASTECEKKNQDTITTKKYI

Chart 1. Amino acid sequences of different fragments of human BRCA2 protein tested for their abilities to bind to the components of the ISGF3 complex.

2. Evaluation of direct binding between BRCA2 and ISGF3 components by yeast 2-hybrid analysis. We employed BD Clontech Matchmaker Gold yeast two hybrid system for this purpose. We cloned the five BRCA2 ORF fragments described in the previous section into pGBKT7 DNA-BD cloning vector. Similarly we have cloned IRF9 and Stat-2 (wild type and Y690A mutant) ORFs into pGADT7 AD cloning vector. We are also cloned Stat-1 ORFs into pGADT7 vector. The yeast cells were co-transfected individually with pGADT7 fusion construct and pGBKT7 fusion construct. Yeast cells were plated onto synthetic dropout medium lacking leucine, tryptophan, and histidine in the presence of 5-bromo-4-chloro-3-indolyl-ft-D-galactopyranoside (X- α -Gal; Clontech) to select for yeast containing weaker interacting proteins. Yeast cells were also plated onto synthetic dropout medium lacking leucine, tryptophan, histidine, and adenine in the presence of 5-bromo-4-chloro-3-indolyl-ft-D-galactopyranoside (X- α -Gal; Clontech) to select for yeast containing stronger interacting proteins. The positive control (supplied with the reagent kit) used was SV40 T-antigen and p53, known to interact very



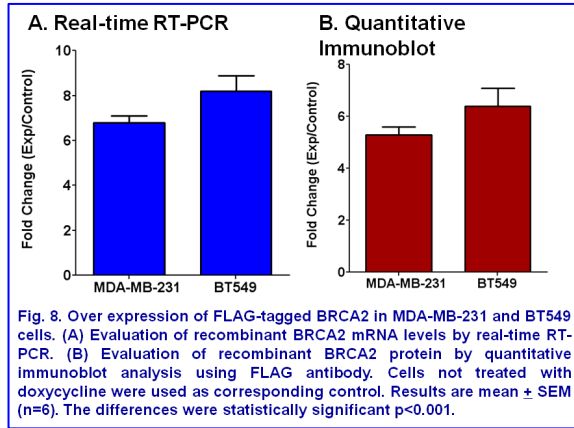
strongly. The negative controls used were cells co-transfected with empty pGADT7/pGBKT7 vector, untransformed AH109 cells and singly transformed yeast cells. β -Galactosidase assays were done using the Beta Glo Assay reagents and protocols (Promega) to detect β -Galactosidase activity in the co-transfected yeast cell extracts. Yeast cells as well as the Beta-Glo reagent were brought to room temperature. Equal volumes of the reagent and the yeast cell culture were added together. The sample contents were mixed for 30 seconds. Samples were then incubated for 30 min at room temperature and the luciferase activity was measured using a luminometer. Both the cell growth data (not shown) as well as the beta-glo assay data (Fig. 7) suggest that none of the five BRCA2 fragments directly binds to the individual

component proteins of the ISGF3 complex in the yeast cells. These data may suggest that BRCA2 perhaps interacts with the ISGF3 complex once it is formed as a trimer.

3. Generation of MDA-MB-231 and BT-549 cell derivatives inducibly over expressing BRCA2 and their characterization. We have generated lentiviral constructs for full length BRCA2 with a C-terminal FLAG tag, as described before for SLUG [20, 21]. We transfected MDA-MB-231 and BT549 cells constitutively expressing tet-repressor protein with this construct, selected for stable transfectants and then evaluated the mRNA and protein levels of recombinant BRCA2 in the presence or absence of doxycycline. We evaluated recombinant BRCA2 mRNA levels with primers designed from BRCA2 ORF and the FLAG epitope. These primers did not amplify the native BRCA2 in the cells. We performed real-time RT-PCR analysis for this evaluation. Total RNA was isolated from the cultured cells using TRIzol reagent (Invitrogen). The cDNA was synthesized from 1 μ g of total RNA using the iScript cDNA Synthesis kit (Bio-Rad). Real-time PCR quantification was performed following standard protocols using Syber green dye (BioRad). RT-PCR was performed in the iCycler (BioRad): 95°C for 10 min, 40 cycles of 15 s at 95°C, 30 s at 51°C, 30 s at 72°C followed by 1 min at 95°C, 30 s at 55°C and 30 s at 95°C. The fold change over control samples was calculated using CT , ΔCT , and $\Delta\Delta CT$ values [20, 21]. β -Actin RNA was used as an endogenous control. For the

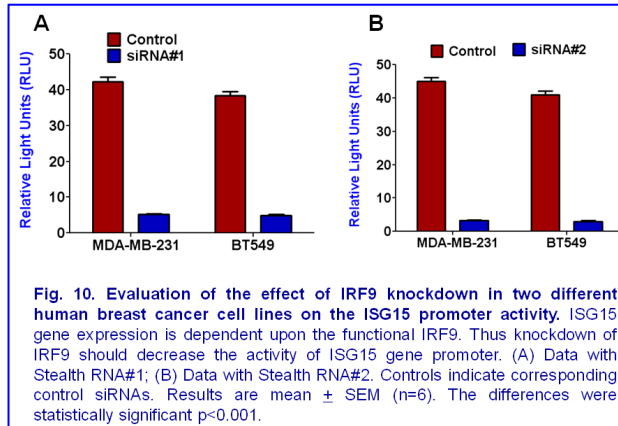
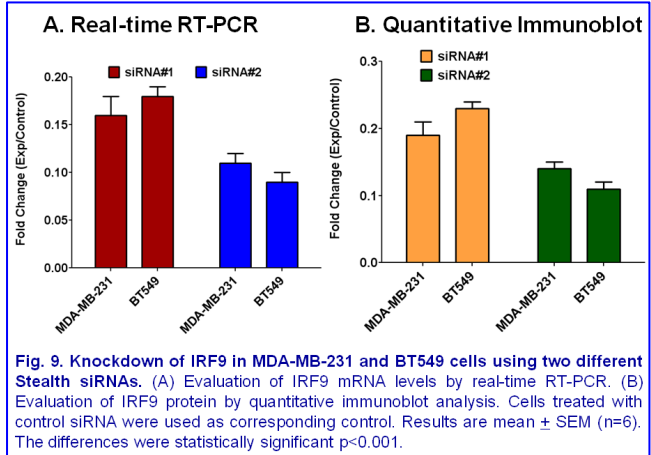
evaluation of BRCA2 protein levels in the breast cancer cell lines by Western blotting with FLAG antibody, protein bands were developed using IR Dye 800 conjugated secondary antibody

(LI-COR Biosciences), and visualized using LI-COR's Odyssey Infrared Imaging System. Quantitation and analysis of bands were performed using Odyssey's software. β -actin was used as normalization control. Figs. 8A and 8B show the over expression of recombinant BRCA2 mRNA and protein in these stably transfected cells.



4. Knockdown of IRF9 gene expression in the control and the BRCA2-over expressing cells. IRF9 siRNAs and corresponding control siRNAs were designed using the Block-IT RNAi designer

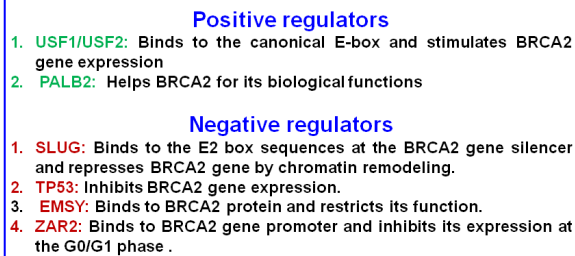
software (Invitrogen) and purchased from Invitrogen. The nucleotide sequences of these siRNAs and respective control RNAs used in GAGCUCUUCAGAACCGCCUACUUCU-3'/5'-AGAAGUAGGCGGUUCUGAAGAGCUC-3'; Control961: 5'-GAGUCCUGAAACCCGUCCAUCUCU-3'/5'-AGAGAAUGGACGGGUUUCAGGACUC-3'; Stealth1025: 5'-CACCGAAGUCCAGGU AACACUGAA-3'/5'-UUCAGUGUUACCUGGAACUUCGGUG-3'; Control1025: 5'-CACGAACUUGACAUGACAUCGGGAA-3'/5'-UUCCGGAUGUCAUGUCAAGUUCGUG-3'. Transfection of these siRNAs into the breast cells was done by lipofection using the Lipofectamine 2000 (Invitrogen) as per the manufacturer's instructions. Briefly, cells were transfected at ~50% confluence using



MDA-MB-231 and BT549 cells with the Stealth siRNAs used. Fig. 10 shows the inhibition of the ISG15 gene promoter activity in the IRF9 knocked down cells. We evaluated ISG15 gene promoter activity in transiently transfected cells by dual luciferase assay [20, 21]. We PCR

amplified human ISG15 gene promoter from total DNA isolated from MDA-MB-231 cells with specific primers. The amplified DNA was cloned into the pCR4.0/TOPO vector (Invitrogen) and subsequently subcloned into the Hind III/Pst I sites of pRL-Null vector (Promega). Cells were seeded on 24-well tissue culture plates in triplicate and allowed to grow overnight to reach 90% to 95% confluence. The following day cells were transfected with pGL3-Control and pRL-ISG15 promoter construct using Lipofectamine 2000 transfection reagent (Invitrogen). Forty-eight hours later, luciferase activities were measured using the Dual Luciferase Reporter Assay System (Promega) [20, 21]. *Renilla* Luciferase activity was normalized to firefly luciferase activity [20, 21].

Fig. 11. Major regulators of BRCA2 gene expression and function



5. Knockdown of BRCA2 levels in the MCF7 cells by overexpressing ZAR2 or SLUG, made these cells resistant to IFN- α . BRCA2 is known to be regulated by several factors (Fig. 11). One of the major regulators we recently discovered is ZAR2 [22]. This C4-type zinc finger protein is expressed from the reverse promoter activity of BRCA2 gene (Fig. 12) and negatively reregulates BRCA2 gene expression [22]. Another negative

regulator for BRCA2 we discovered is the C2H2 type transcriptional repressor SLUG [20]. We found that ectopic expression of ZAR2 or SLUG in MCF7 cells knockdown BRCA2 along with ISG15 (Figs. 13 and 14). Interferon- α (1000 IU/ml) induced stimulation of ISRE-containi

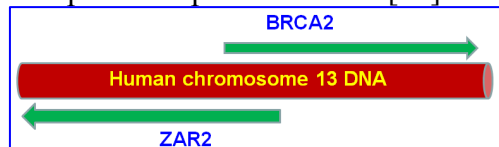
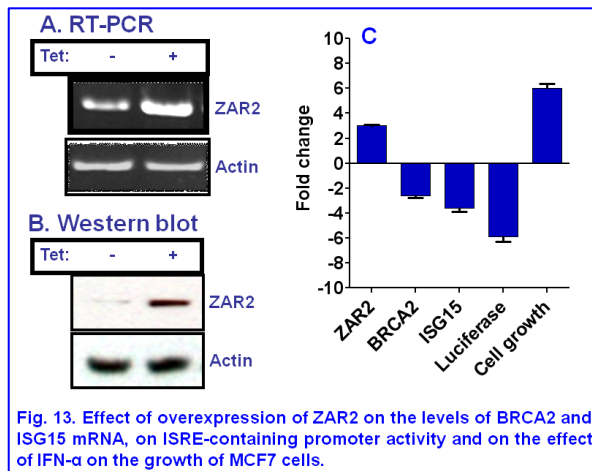


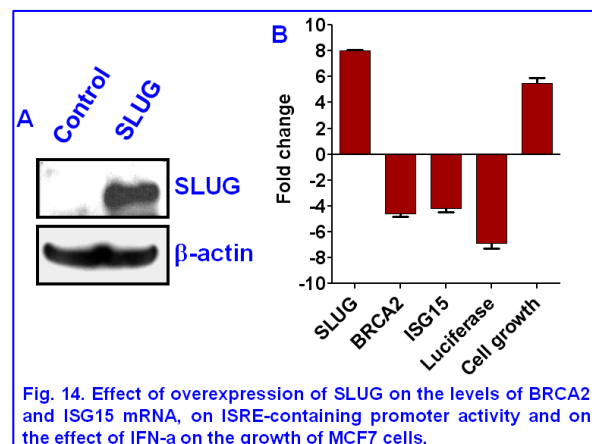
Fig. 12. A novel C4-type zinc finger protein ZAR2 is transcribed from the reverse activity of the BRCA2 gene overlapping bi-directional promoter at chromosome 13. ZAR2 negatively regulates BRCA2 gene expression.



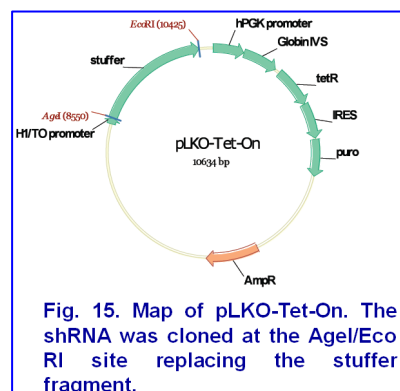
ZAR2 and SLUG expressing cells (Figs. 13 and 14).

Task#3

Evaluation of the antiproliferative effects of type I interferons against tumors developed by BRCA2 positive and BRCA2 negative cells in the nude mice xenograft model. (Months 25-36)



1. Development of MDA-MB-231 cells expressing shRNA against BRCA2 and their characterization. (Months 25-27).



For inducible knockdown of BRCA2 in MCF7, MDA-MD-231 and BT549 cells, we employed pLKO-Tet-On plasmid (Fig. 15; Addgene). This single plasmid has all the necessary components for the inducible expression of shRNA in target cells. In the absence of doxycycline, shRNA expression is repressed by the TetR protein constitutively expressed also from this plasmid. The cells were treated with 1000 IU/ml of IFN- α for 24 h. Six independent BRCA2-knocked down cell populations and corresponding control shRNA construct-transfected cells were used. We evaluated the levels of mRNAs and proteins of several IFN-regulated genes in these cells.

RNA levels were assayed by real-time RT-PCR. Beta-actin was used as normalization control. GAPDH and BRCA1 were used as references. For protein evaluation Bands were developed using IR Dye-conjugated secondary antibody (LI-COR Biosciences), and visualized using LI-COR's Odyssey Infrared Imaging System. Quantitation and analysis of bands were performed using Odyssey's software. The levels of the mRNAs

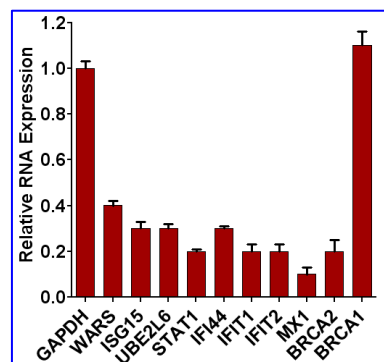


Fig. 16. Evaluation of several IFN regulated mRNA levels in MDA-MB-231 cells with or without knockdown of BRCA2. Results are mean \pm SEM (n=6). Fold changes observed were statistically significant ($p < 0.001$).

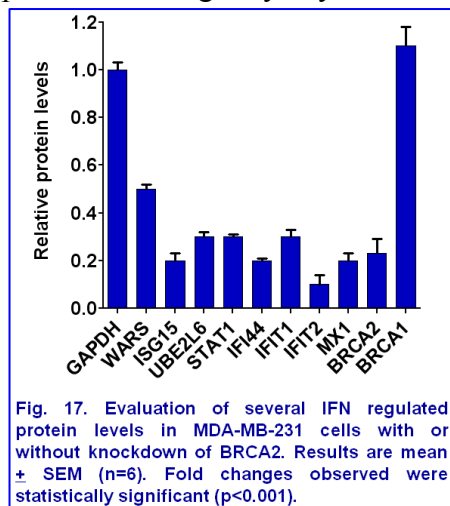


Fig. 17. Evaluation of several IFN regulated protein levels in MDA-MB-231 cells with or without knockdown of BRCA2. Results are mean \pm SEM (n=6). Fold changes observed were statistically significant ($p < 0.001$).

and the proteins of WARS, ISG15, UBE2L6, STAT1, IFI44, IFIT1, IFIT2 and MX1 were decreased significantly upon knockdown of BRCA2 in the cells (Figs. 16 and 17). There was no change in the levels of these mRNAs and proteins in the absence of doxycycline. In the presence of doxycycline and IFN- α , the activities of ISG15 and UBE2L6 gene promoters were also inhibited in the BRCA2-knocked down cells (Figs. 18 and 19).

2. Establishment of subcutaneous tumors in nude mice with wild type, or BRCA2 knocked down MDA-MB-231 cells. (Months 28-31).

We stably transfected MDA-MB-231 and BT549 cells with pCMV-tdTomato plasmid (Clontech) to express the red tdTomato protein in these cells (Fig. 20). We developed the tumor in BALB/c nude mice with human breast cancer cell MDA-MB-231 with or without knockdown of BRCA2 in these cells. 5×10^6 MDA-MB-231 cells were injected into the mammary fat pad of nude mice as described [23]. Tumor developed after 6 weeks.

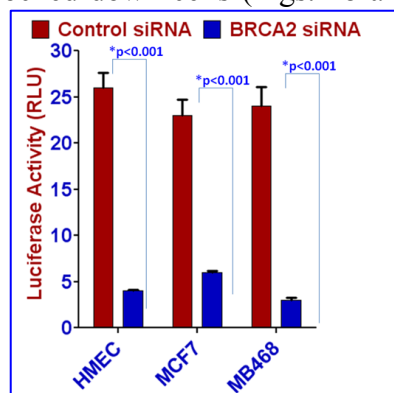
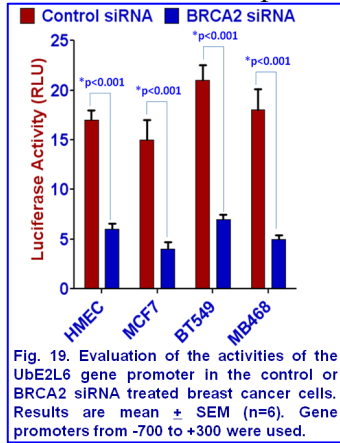
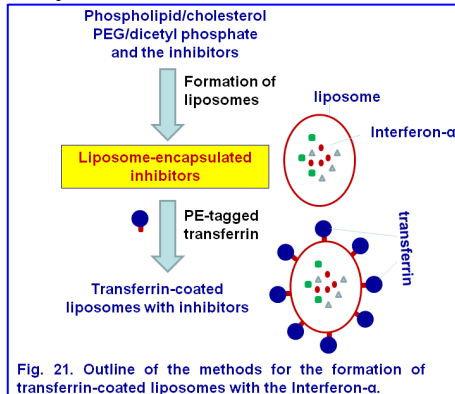


Fig. 18. Evaluation of the activities of the ISG15 gene promoter in the control or BRCA2 siRNA treated breast cancer cells. Results are mean \pm SEM (n=6). Gene promoters from -700 to +300 were used.

3. Interferon treatment of the mice. (Months 32-34). We tested the usefulness of the transferrin-coated liposomes in delivering interferon-alpha to the experimental tumors *in vivo*



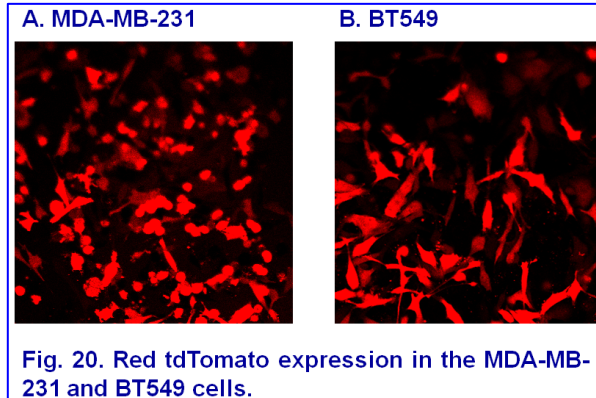
animals that did not receive any treatment. The next two groups received transferrin-coated liposomes with or without IFN- α (200 IU/per gm animal body weight) intravenously through the tail vein [23]. For one set of experiments, tumors were excised from the animals after 1 week post-treatment and the tumor cells were analyzed for ISG15, STAT1, IFI44, IFIT1,



were performed 6 times (for 3 weeks). Tumor xenografts were measured with calipers twice a week, and tumor volumes were determined using the formula: $(\text{length} \times \text{width}^2) \times (\pi/6)$. Fifty-60 days after the last treatment, the animals will be anesthetized with 3% isoflurane-air mixture and killed by cervical dislocation. Tumor samples were stained with hematoxylin and eosin for morphologic observation. The data are being averaged from at least 2 independent experiments. A paired two-tailed *t*-test were used for analysis of the data. Values of $P < 0.05$ are considered significant. The expression of tdTomato in the tumor forming cells (see above) allowed us to locate tumor cells and to measure tumor growth by utilizing Carestrom *in vivo* imaging system at Meharry small animal

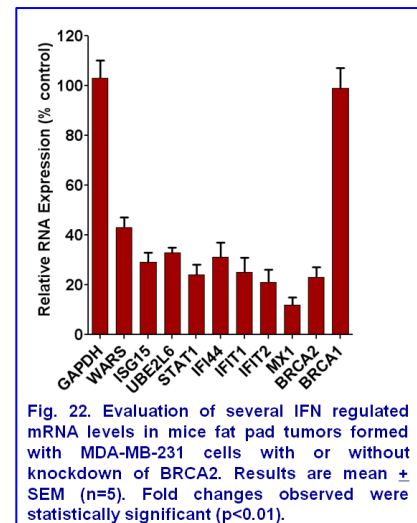
(Fig. 21). This techniques involves the use of transferrin (TF)-pendant-type polyethyleneglycol (PEG)-liposomes (TF-PEG-liposomes), in which TF was covalently linked to the distal terminal of PEG chains on the external surface of PEG-liposomes as a carrier for *in vivo* cytoplasmic targeting to the tumor cells [24, 25] (Fig. 21). TF is a glycoprotein, which transports ferric ion in the body. It is known that the TF receptor concentration on tumor cells is much higher than that on normal cells [24, 25]. The tumor bearing mice

were divided into three groups of 5 animals each. One group was control

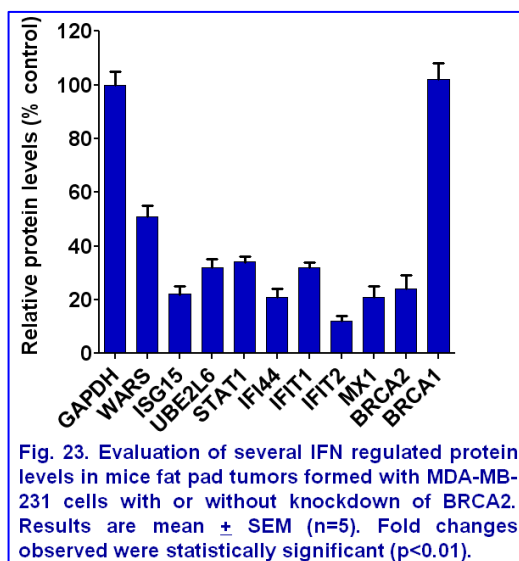


IFIT2, and MX1 mRNA and protein levels. Our results indicated that the transferrin-coated liposomes containing IFN- α were efficient in stimulating the interferon-stimulated genes tested in the tumor cells transfected with control pLKO-Tet-On but not with the BRCA2 shRNA containing plasmid *in vivo* (Figs. 22 and 23).

4. Analysis of the excised tumors for weights and histochemical parameters. (Months 34-36). This part of the specific aim is ongoing. Treatments



imaging core facility. Preliminary data indicate significant decrease in the growth of the tumors with BRCA2 knocked down cells.



Key Research Accomplishments

- N-terminal sequences of human BRCA2 protein appears to be involved in the direct binding of this protein with the ISGF3 protein complex as was revealed by pull down analysis.
- None of the fragments of BRCA2 protein could directly bind with individual components of the ISGF3 complex in the yeast 2-hybrid analysis, suggesting that BRCA2 perhaps binds with the ternary complex after it is formed.
- We were successful in over expressing

FLAG-tagged BRCA2 protein in an inducible manner in MDA-MB-231 and BT549 cells.

- We successfully knocked down IRF9 in the breast cancer cells.
- Knock down of IRF9 negatively affected ISG15 gene promoter activity in the knocked down cells.
- **We derived that ISGF3 ternary complex (P-STAT1/P-STAT2/IRF9) is formed on BRCA2 and the quaternary complex is imported to the nucleus (Fig. 24).**
- **We also predict that BRCA2 helps loading the ISGF3 complex to the target gene promoter (Fig. 24).**

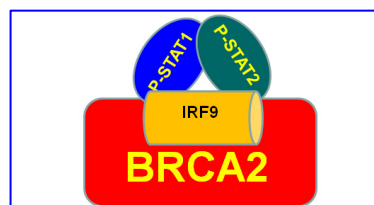


Fig. 24. We derived that ISGF3 ternary complex (P-STAT1/P-STAT2/IRF9) is formed on BRCA2 and the quaternary complex is imported to the nucleus. We also predict that BRCA2 helps loading the ISGF3 complex to the target gene promoter.

REPORTABLE OUTCOMES:

Publication:

1. Mittal M. K., Singh, K., Misra, S. and **Chaudhuri, G.** (2011) SLUG-induced elevation of D1 cyclin in breast cancer through the inhibition of its ubiquitination. ***J. Biol. Chem.* 286**, 469-479. **Journal Impact factor: 5.325.**
2. Hall, M. 3rd, Misra, S., Chaudhuri, M., and **Chaudhuri, G.** (2011) Peptide aptamer mimicking RAD51-binding domain of BRCA2 inhibits DNA damage repair and survival in *Trypanosoma brucei*. ***Microb. Pathog.* 50**, 252-262. **Journal Impact factor: 2.324.**
3. Farrow, A. L., Rana, T., Mittal, M. K., Misra, S., and **Chaudhuri, G.** (2011) *Leishmania*-induced repression of selected non-coding RNA genes containing B-

box element at their promoters in alternatively polarized M2 macrophages. ***Mol. Cell. Biochem.* 350**, 47-57. **Journal Impact factor: 1,896.**

4. Rana, T., Misra, S., Mittal, M. K., Farrow, A. L., Wilson, K. T., Linton, M. F., Fazio, S., Willis, I. M., and **Chaudhuri, G.** (2011) Mechanism of down-regulation of RNA polymerase III-transcribed non-coding RNA genes in macrophages by *Leishmania*. ***J. Biol. Chem.* 286**, 6614-6626. **Journal Impact factor: 5.325.**
5. Misra, S. Sharma, S., Agarwal, A., Khedkar, S. V., Tripathi, M. K., Mittal M. K., and **Chaudhuri, G.** (2010) Cell cycle-dependent regulation of the bi-directional overlapping promoter of human BRCA2/ZAR2 genes in breast cancer cells. ***Mol. Cancer.* 9**, 50. **Journal Impact factor: 4.16.**
6. Ochieng, J, and **Chaudhuri, G.** (2010) Cystatin superfamily. ***J. Health Care Poor Underserved.* 21**, 51-70.
7. Mittal, M. K., Myers, J. N., Bailey, C. K., Misra, S., and **Chaudhuri, G.** (2010) Mode of action of the retrogene product SNAI1P, a SNAIL homolog, in human breast cancer cells. ***Mol. Biol. Rep.* 37**, 1221-1227. **Journal Impact factor: 2.038.**
8. Kaneko, H., Dridi, S., Tarallo, V., Gelfand, B. D., Fowler, B. J., Cho, W. G., Kleinman, M. E., Ponicsan, S. L., Hauswirth, W. W., Chiodo, V. A., Karikó, K., Yoo, J. W., Lee, D. K., Hadziahmetovic, M., Song, Y., Misra, S., **Chaudhuri, G.**, Buaas, F. W., Braun, R. E., Hinton, D. R., Zhang, Q., Grossniklaus, H. E., Provis, J. M., Madigan, M. C., Milam, A. H., Justice, N. L., Albuquerque, R. J., Blandford, A. D., Bogdanovich, S., Hirano, Y., Witta, J., Fuchs, E., Littman, D. R., Ambati, B. K., Rudin, C. M., Chong, M. M., Provost, P., Kugel, J. F., Goodrich, J. A., Dunaief, J. L., Baffi, J. Z., and Ambati, J. (2011) DICER1 deficit induces Alu RNA toxicity in age-related macular degeneration. ***Nature.* 471**, 325-330. **Journal Impact factor: 34.48.**

Meeting abstracts:

1. Mittal, M. K., Singh, K. and **Chaudhuri, G.** (2009) Mechanisms of SLUG-induced drug resistance development in breast cancer cells. **Presented as poster at the 2009 San Antonio Breast Cancer Symposium (SABCS) held in Henry B. Gonzalez Convention Center, San Antonio, Texas, USA, December 9-13, 2009.**
2. Bailey, C. K., Mittal, Mukul, Misra, Smita and **Chaudhuri, G.** (2010) Reduction of the invasive phenotype of SNAI-over expressing human breast cancer cells by peptide aptamer-mediated inhibition of SNAI protein functions. **Presented at the AACR Annual meeting in Washington DC on April 17-21, 2010.**
3. Mittal, M. K., and **Chaudhuri, G.** (2010) Repression of alpha-, beta- and gamma-catenin gene expressions by SNAI2 in human breast cancer cells. **Presented at the AACR Annual meeting in Washington DC on April 17-21, 2010.**

4. Hall, Mack III, Misra, Smita, and **Chaudhuri, G.** (2010) Molecular analysis of the physical interactions of *Trypanosoma brucei* BRCA2 with different RAD51 isoforms. **Presented at the ASBMB Annual meeting in Anaheim, CA on April 24-28, 2010.**
5. Misra, Smita, and **Chaudhuri, G.** (2010) Regulation of BRCA2 gene expression through CpG methylation of its bi-directional promoter induced by endogenous siRNAs. **Presented at the ASBMB Annual meeting in Anaheim, CA on April 24-28, 2010.**
6. Yarlagadda, V., Misra, S., Mittal, M. K., and **Chaudhuri, G.** (2011) Differential Translational Regulation of SLUG mRNA by a uORF in SLUG-High and SLUG-Low Cancer Cells. **Presented at the ASBMB Annual meeting in Washington DC on April 9-13, 2011.**
7. Misra, S., Mittal, M. K., and **Chaudhuri, G.** (2011) Selective modulation of the redox state and thus the repressor function of SLUG by peroxiredoxin 5 at BRCA2 gene silencer in breast cancer cells. **Presented at the ASBMB Annual meeting in Washington DC on April 9-13, 2011.**
8. Mittal, M. K., Misra, S., and **Chaudhuri, G.** (2011) SLUG-induced elevation of D1 cyclin in breast cancer through the inhibition of its ubiquitination. **Accepted for presentation at the Era of Hope Meeting at Orlando World Center Marriott, Orlando, Florida on Aug 2-5, 2011.**
9. Misra, S., Mittal, M. K., and **Chaudhuri, G.** (2011) Cell cycle-dependent regulation of the bi-directional overlapping promoter of human BRCA2/ZAR2 genes in breast cancer cell. **Accepted for presentation at the Era of Hope Meeting at Orlando World Center Marriott, Orlando, Florida on Aug 2-5, 2011.**
10. **Chaudhuri, G.** Misra, S., and Mittal, M. K. (2011) BRCA2 as a determinant of the efficacy of type I interferons against breast cancer cell proliferation. **Accepted for presentation at the Era of Hope Meeting at Orlando World Center Marriott, Orlando, Florida on Aug 2-5, 2011.**
11. Misra, S., Mittal, M. K., and **Chaudhuri, G.** (2011) Repression of retrograde transport of growth promoting receptors by SLUG in breast tumor cells. **Accepted for presentation at the Era of Hope Meeting at Orlando World Center Marriott, Orlando, Florida on Aug 2-5, 2011.**

Conclusion:

We concluded that ISGF3 ternary complex (P-STAT1/P-STAT2/IRF9) is formed on BRCA2 and the quaternary complex is imported to the nucleus. We also predict that BRCA2 helps loading the ISGF3 complex to the target gene promoter.

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APPENDICES: None.